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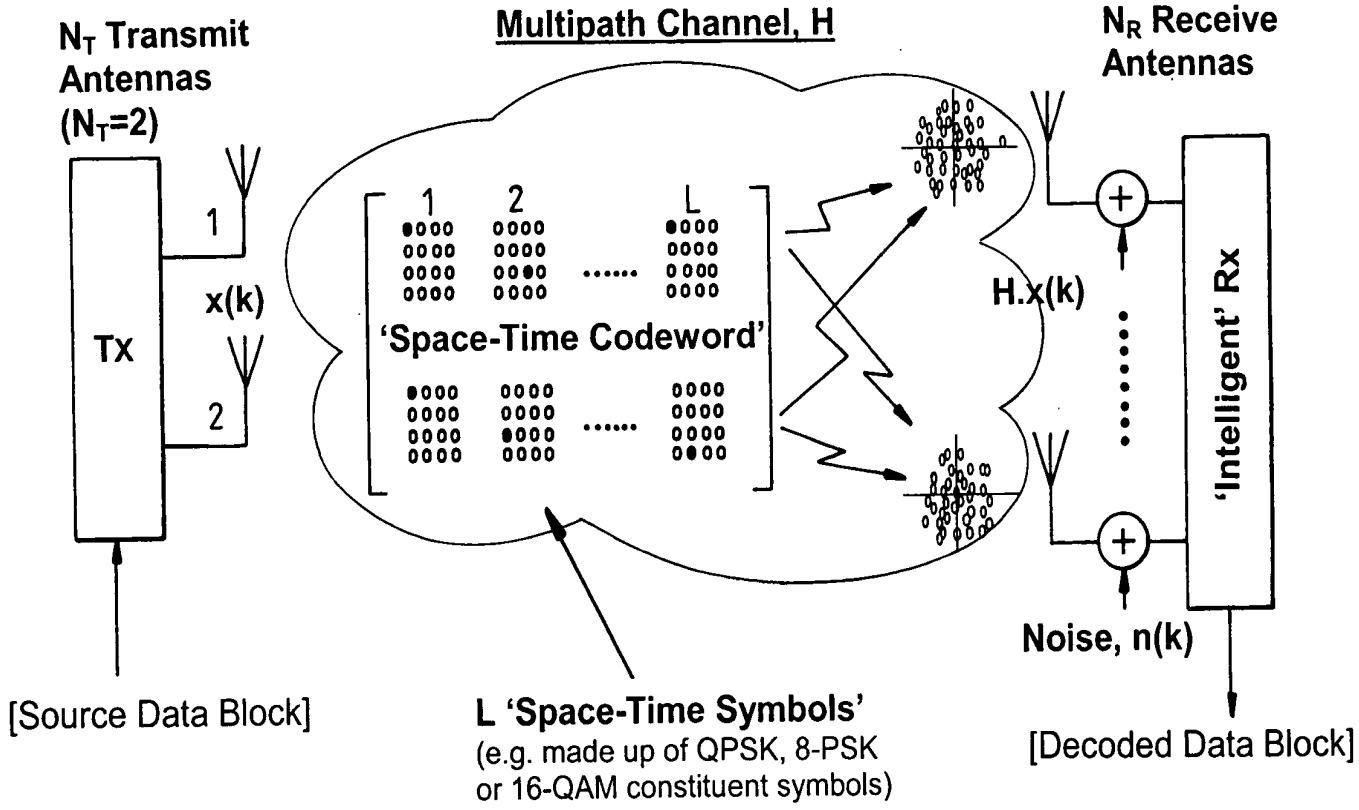
JC16

**Space-Time Coding**
System Model

***Fig. 1***




REPLACEMENT SHEET

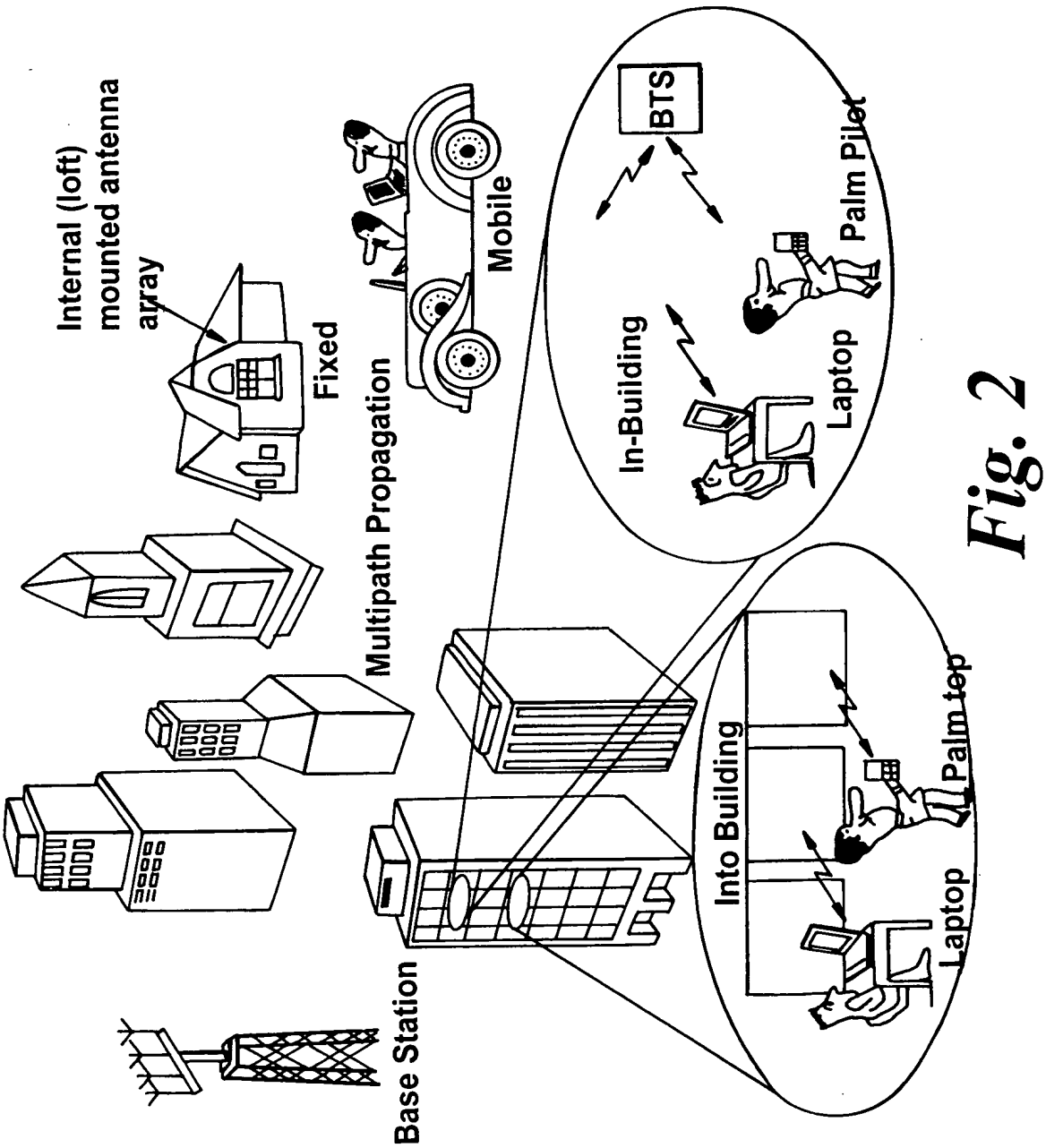

Internal (loft) mounted antenna array
Fixed
Mobile
Multipath Propagation
BTS
Palm Pilot
In-Building
Laptop
Into Building
Palm top
Laptop
Base Station

*Fig. 2*

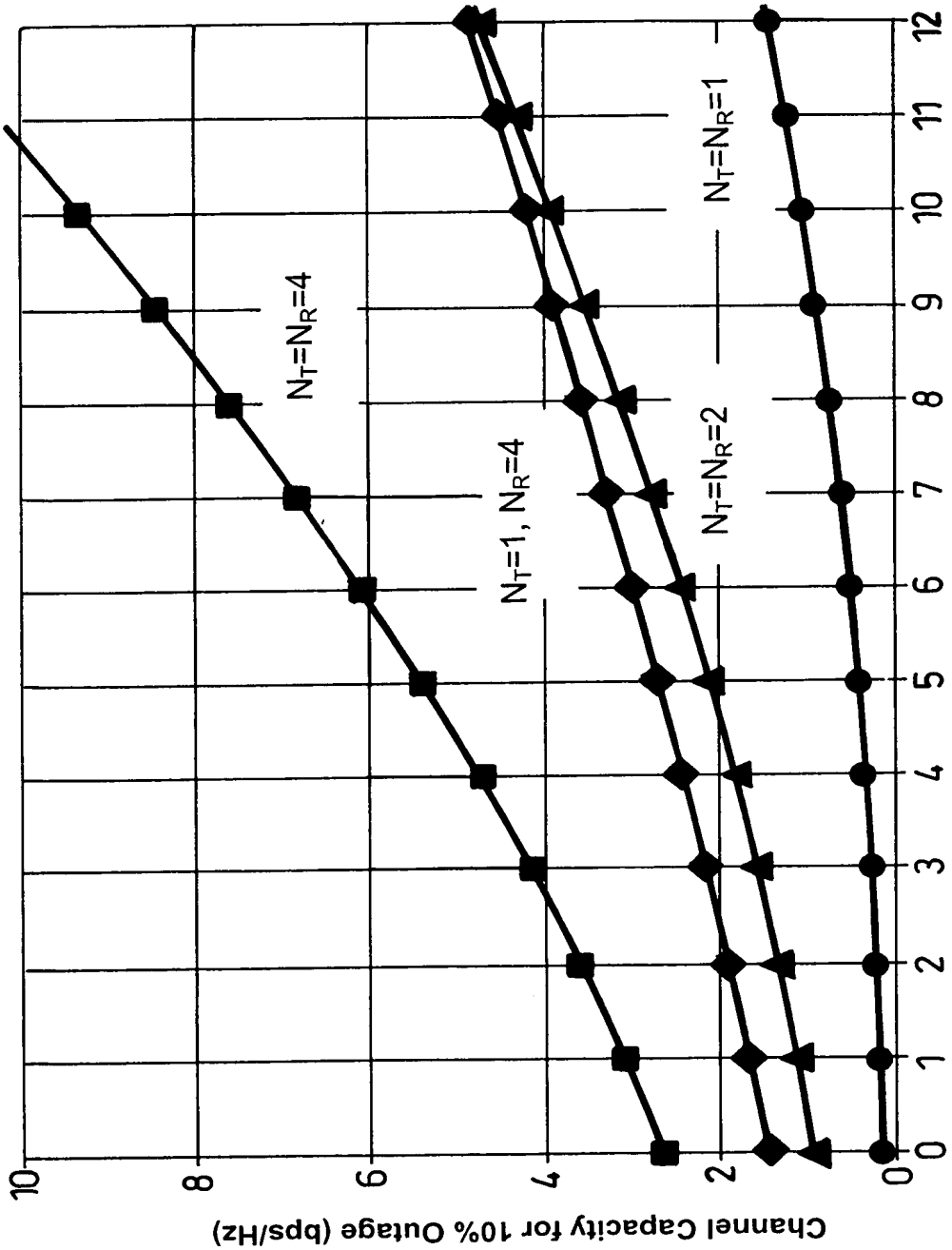

Channel Capacity for 10% Outage (bps/Hz)
SNR per receive antenna (dB)
$N_T=N_R=4$
$N_T=1, N_R=4$
$N_T=N_R=2$
$N_T=N_R=1$

*Fig. 3*

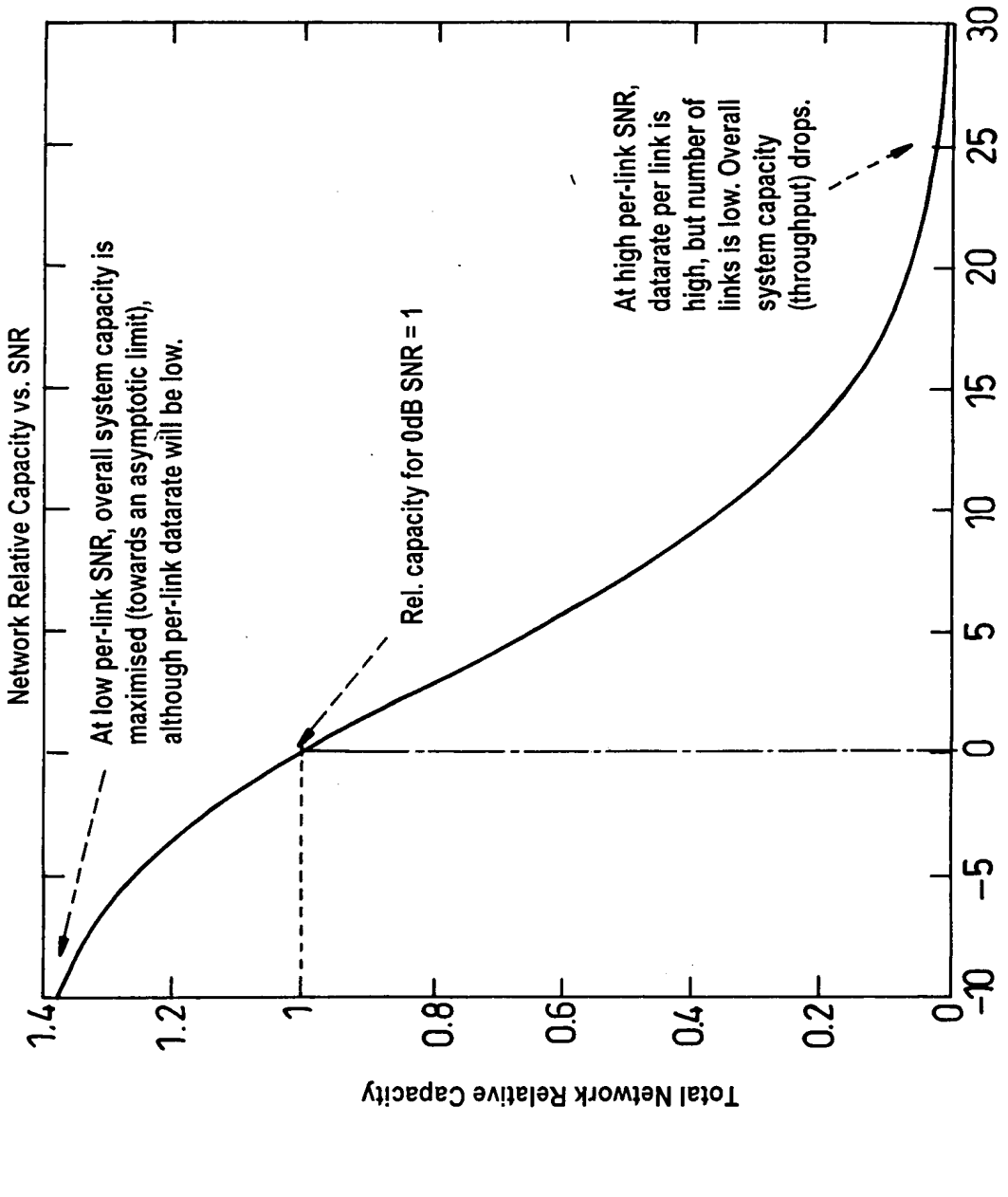

Network Relative Capacity vs. SNR
At low per-link SNR, overall system capacity is maximised (towards an asymptotic limit), although per-link datarate will be low.
Rel. capacity for 0dB SNR = 1
At high per-link SNR, datarate per link is high, but number of links is low. Overall system capacity (throughput) drops.
Total Network Relative Capacity
Link SNR (dB)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-10
-5
0
5
10
15
20
25
30

*Fig. 4*

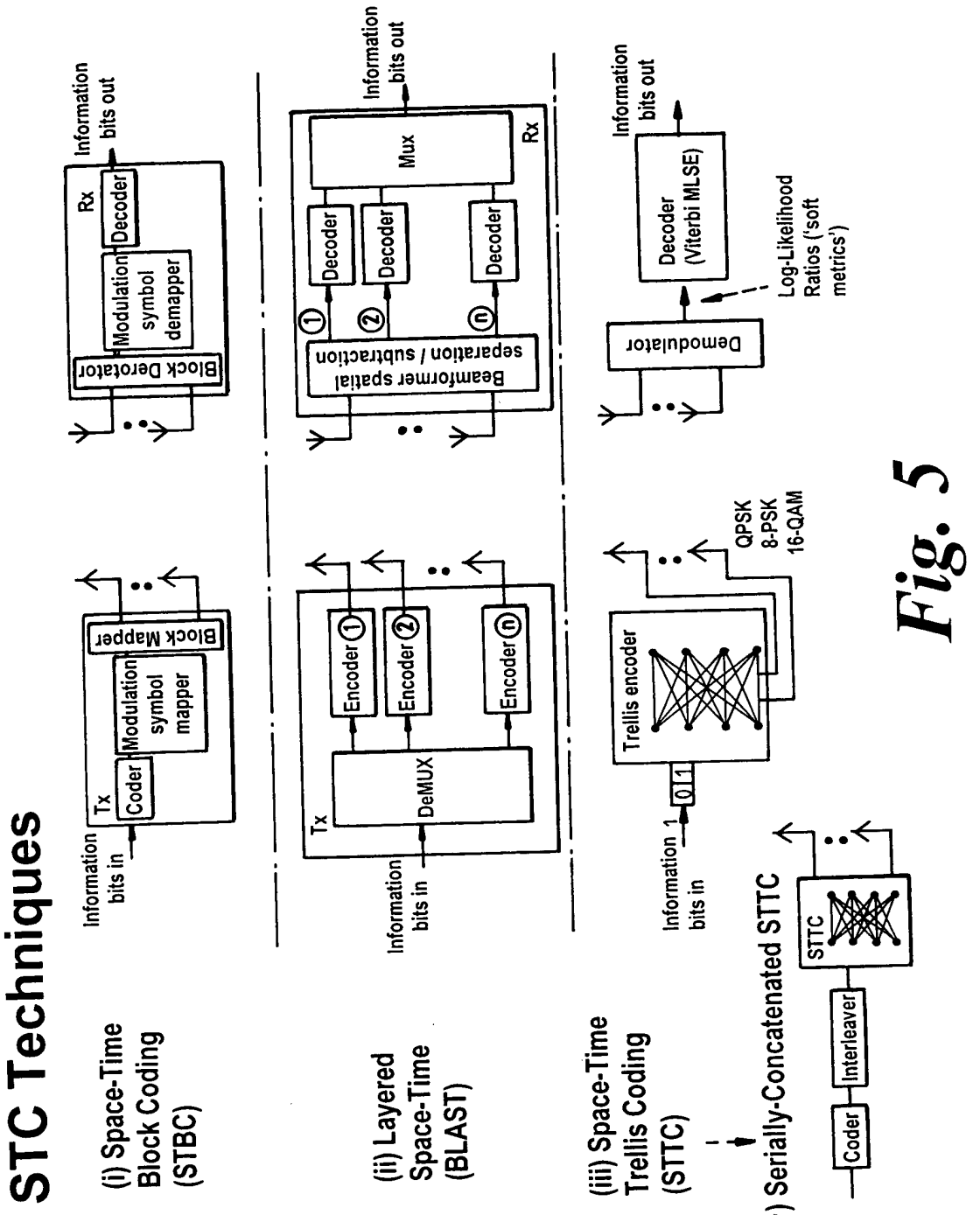

STC Techniques
(i) Space-Time Block Coding (STBC)
Information bits in
Tx
Coder
Modulation symbol mapper
Block Mapper
Rx
Block Derotator
Modulation symbol demapper
Decoder
Information bits out
(ii) Layered Space-Time (BLAST)
Information bits in
Tx
DeMUX
Encoder ①
Encoder ②
Encoder ⓝ
Rx
Beamformer spatial separation / subtraction
Decoder
Mux
Information bits out
(iii) Space-Time Trellis Coding (STTC)
Information bits in
Trellis encoder
QPSK
8-PSK
16-QAM
Demodulator
Decoder (Viterbi MLSE)
Log-Likelihood Ratios ('soft metrics')
Information bits out
(iv) Serially-Concatenated STTC
Coder
Interleaver
STTC

*Fig. 5*

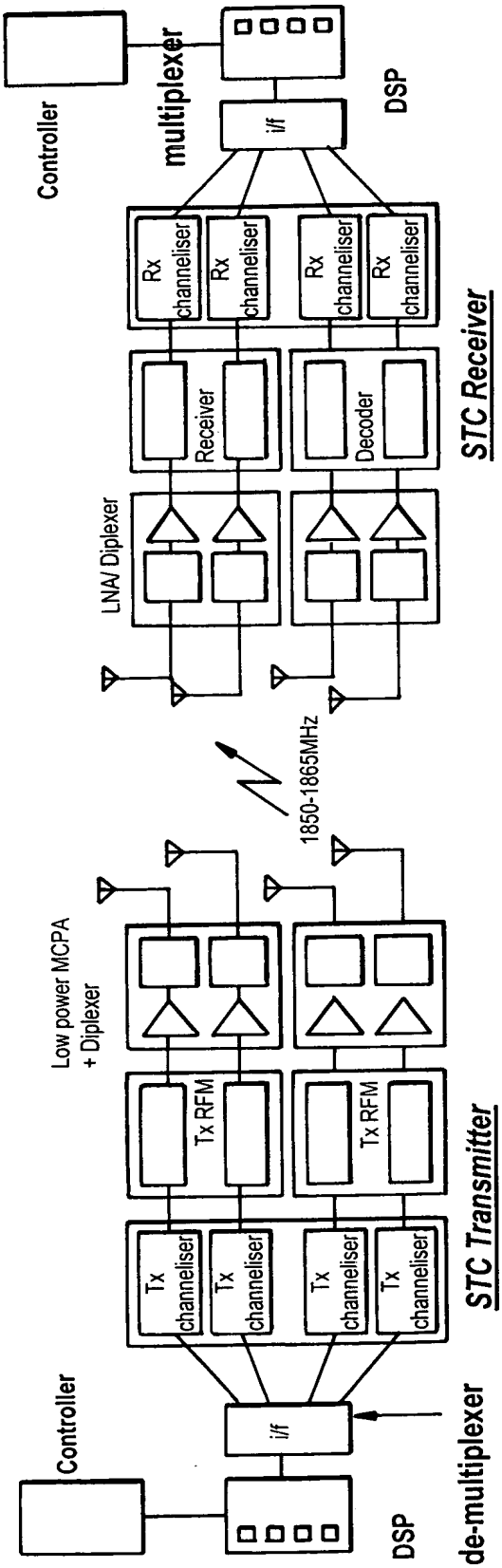

Controller
multiplexer
DSP
i/f
Rx channeliser
Rx channeliser
Rx channeliser
Rx channeliser
Receiver
Decoder
STC Receiver
LNA/ Diplexer
1850-1865MHz
Low power MCPA + Diplexer
Tx RFM
Tx RFM
Tx channeliser
Tx channeliser
Tx channeliser
Tx channeliser
STC Transmitter
Controller
i/f
DSP
de-multiplexer

*Fig. 6*

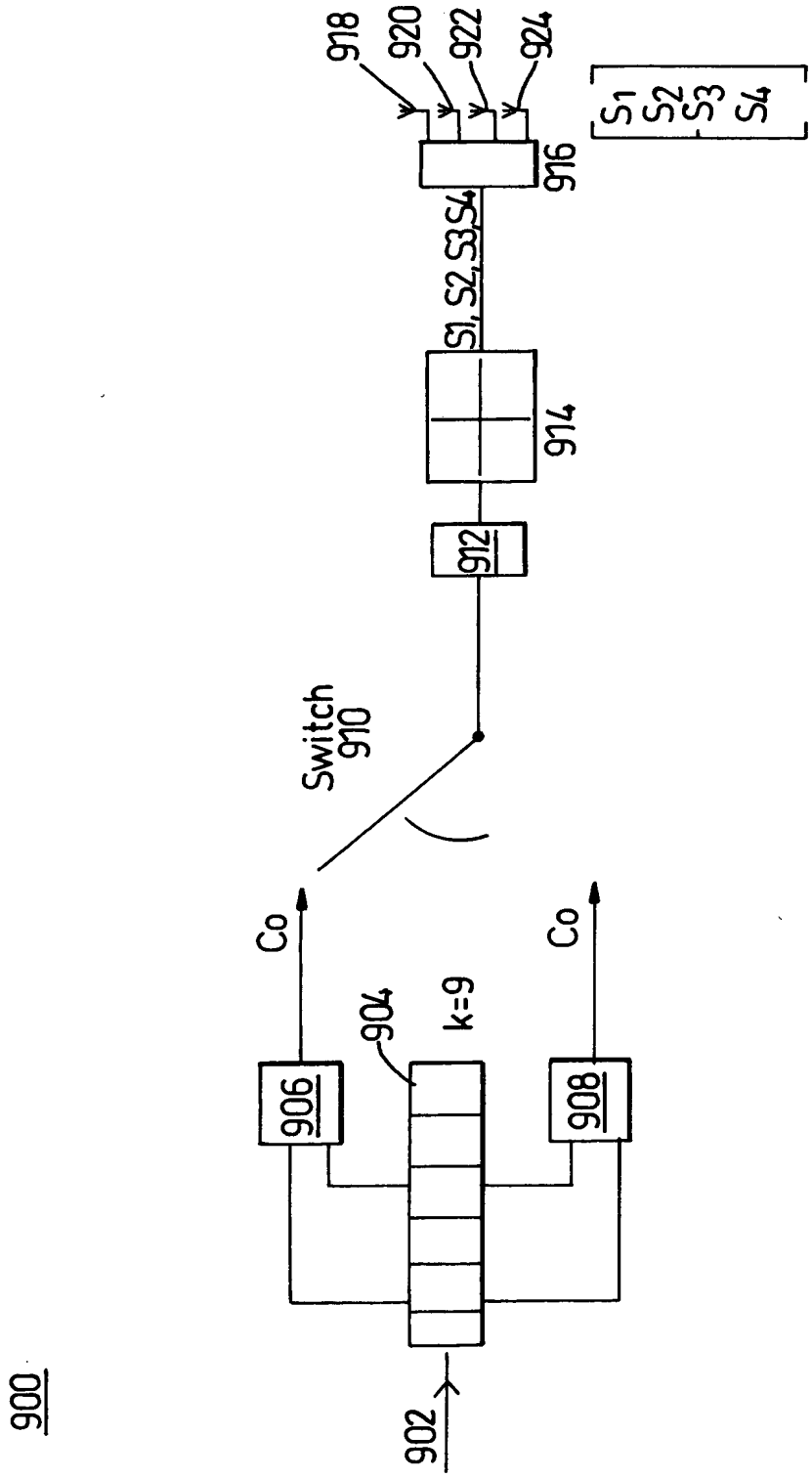

900
902
904
k=9
906
908
Co
Co
Switch
910
912
914
916
S1, S2, S3, S4
918
920
922
924
S1
S2
S3
S4

*Fig. 7*

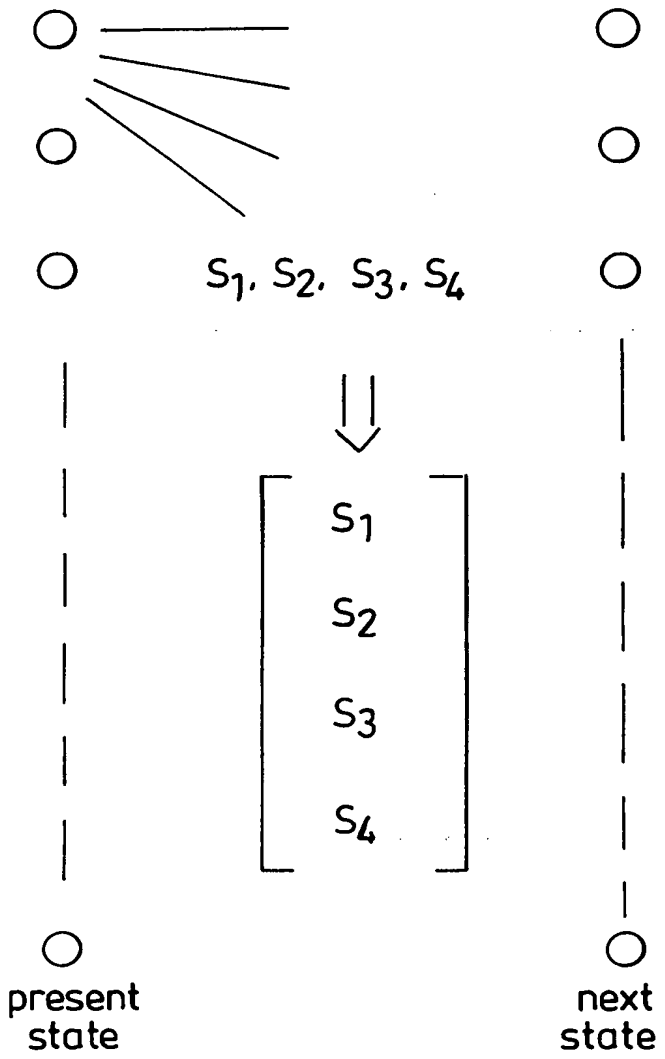



*Fig. 8*

SC-STTC Coder

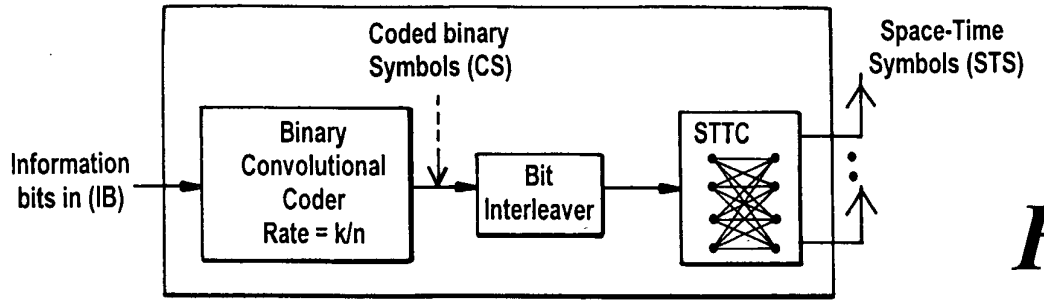
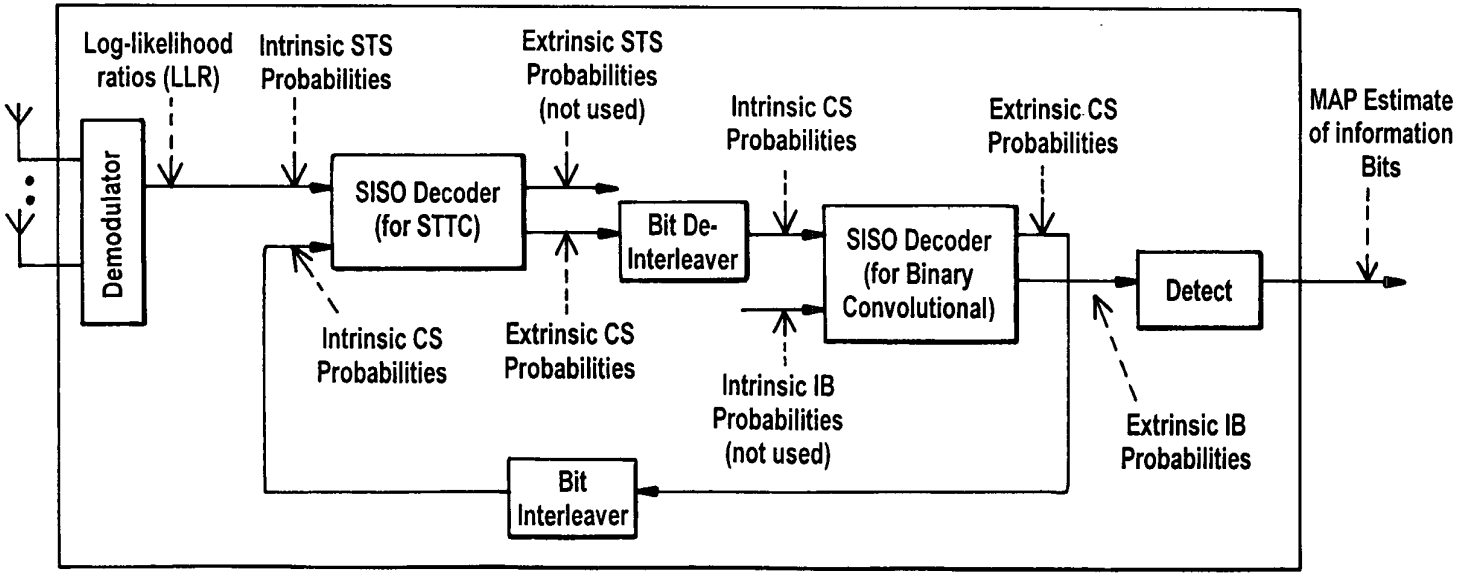



*Fig. 9*

SC-STTC Decoder




REPLACEMENT SHEET

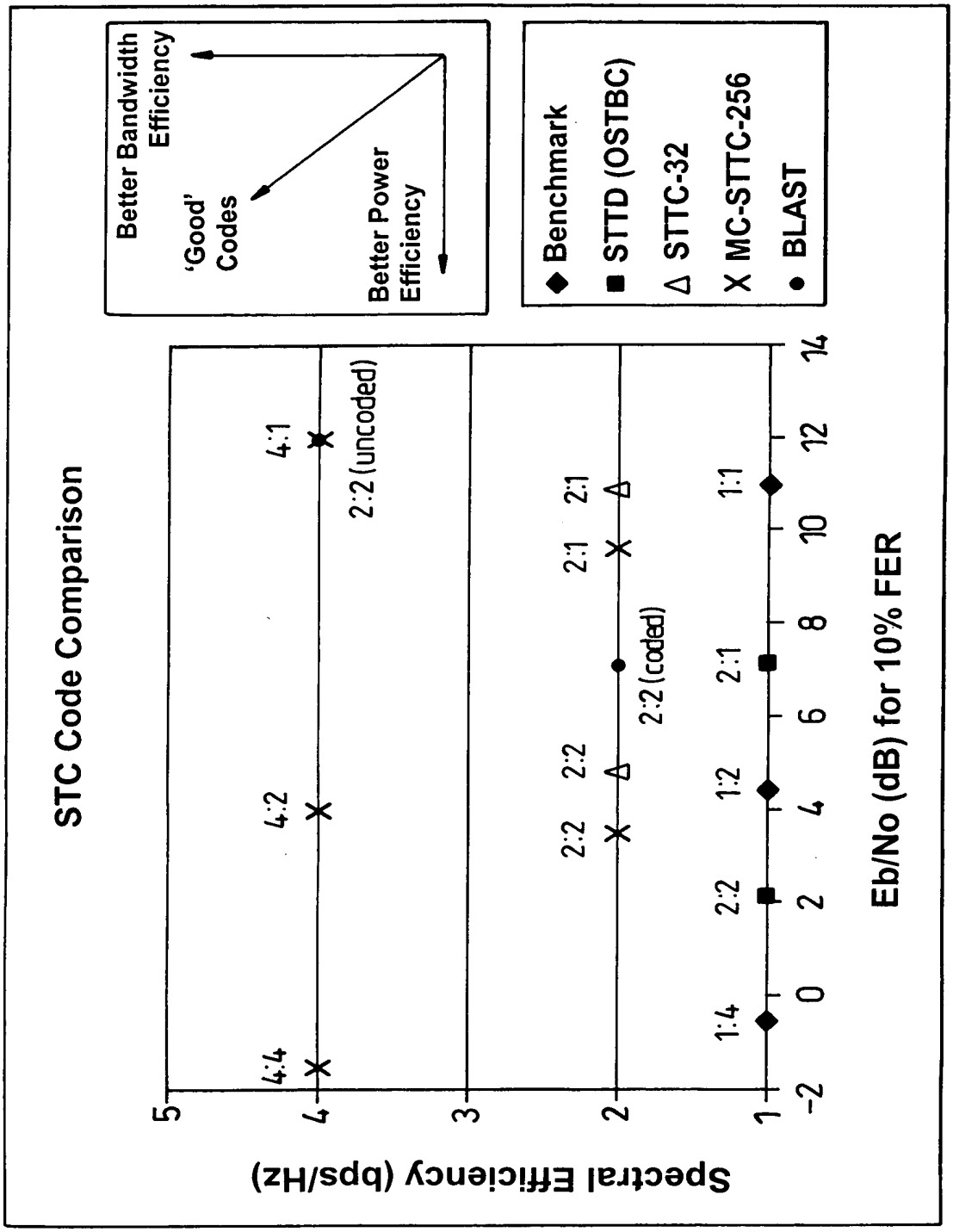

STC Code Comparison
Better Bandwidth Efficiency
'Good' Codes
Better Power Efficiency
◆ Benchmark
■ STTD (OSTBC)
Δ STTC-32
X MC-STTC-256
• BLAST
Spectral Efficiency (bps/Hz)
Eb/No (dB) for 10% FER
4:4
4:2
4:1
2:2 (uncoded)
2:2
2:2
2:1
2:1
2:2 (coded)
1:4
2:2
1:2
2:1
1:1

*Fig. 10*

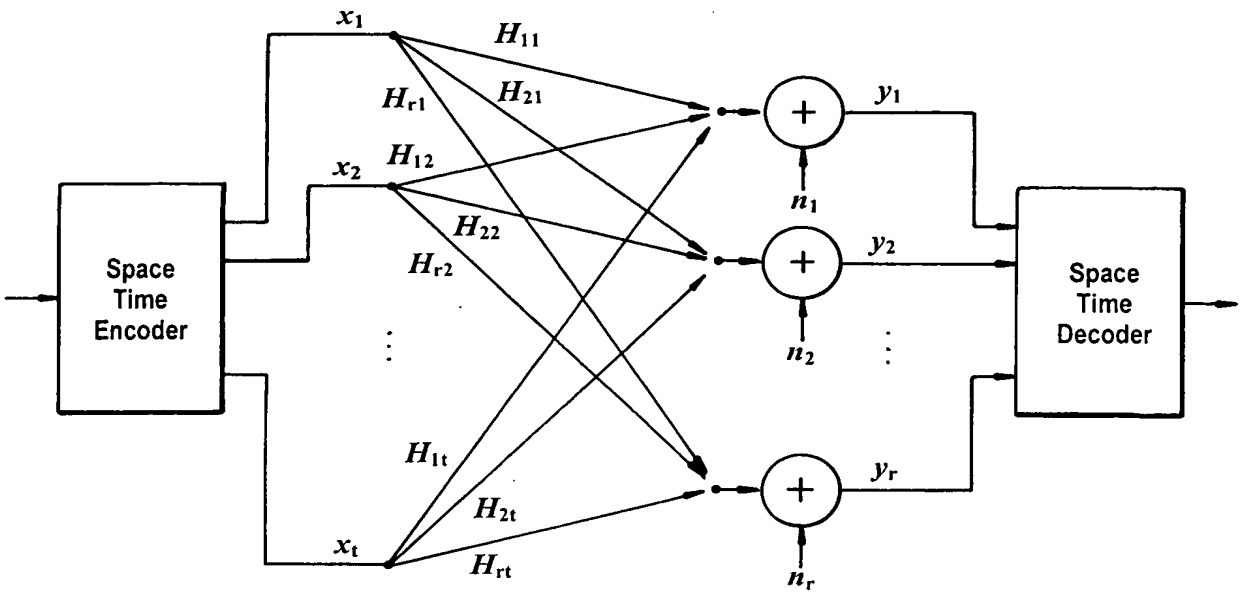

Space Time Encoder
$x_1$
$x_2$
$x_t$
$H_{11}$
$H_{21}$
$H_{r1}$
$H_{12}$
$H_{22}$
$H_{r2}$
$H_{1t}$
$H_{2t}$
$H_{rt}$
$y_1$
$y_2$
$y_r$
$n_1$
$n_2$
$n_r$
Space Time Decoder

*Fig. 11*

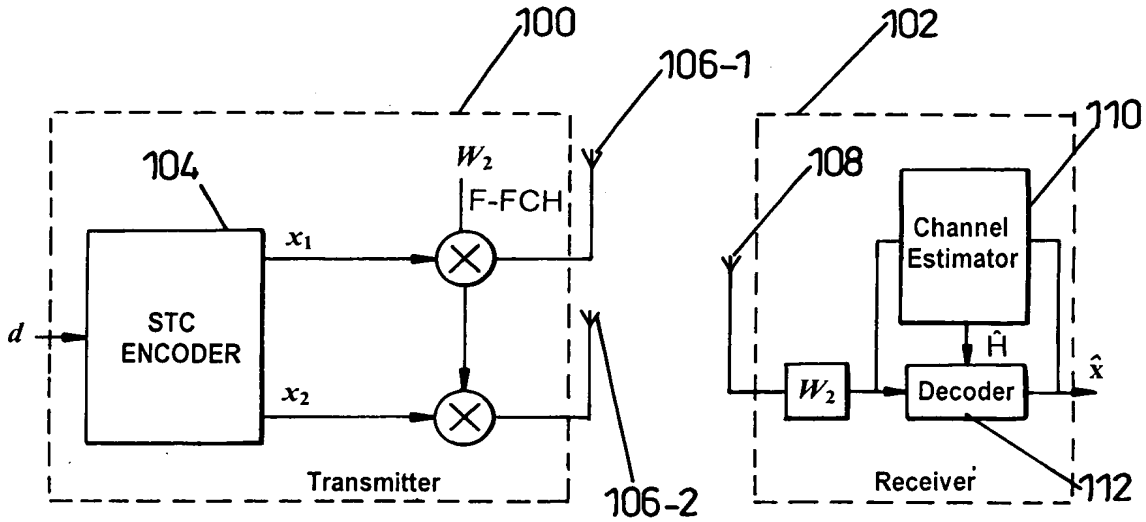

100
102
106-1
110
104
$W_2$
F-FCH
108
Channel Estimator
$x_1$
$x_2$
$d$
STC ENCODER
$\hat{H}$
$\hat{x}$
$W_2$
Decoder
Transmitter
Receiver
106-2
112

*Fig. 12*

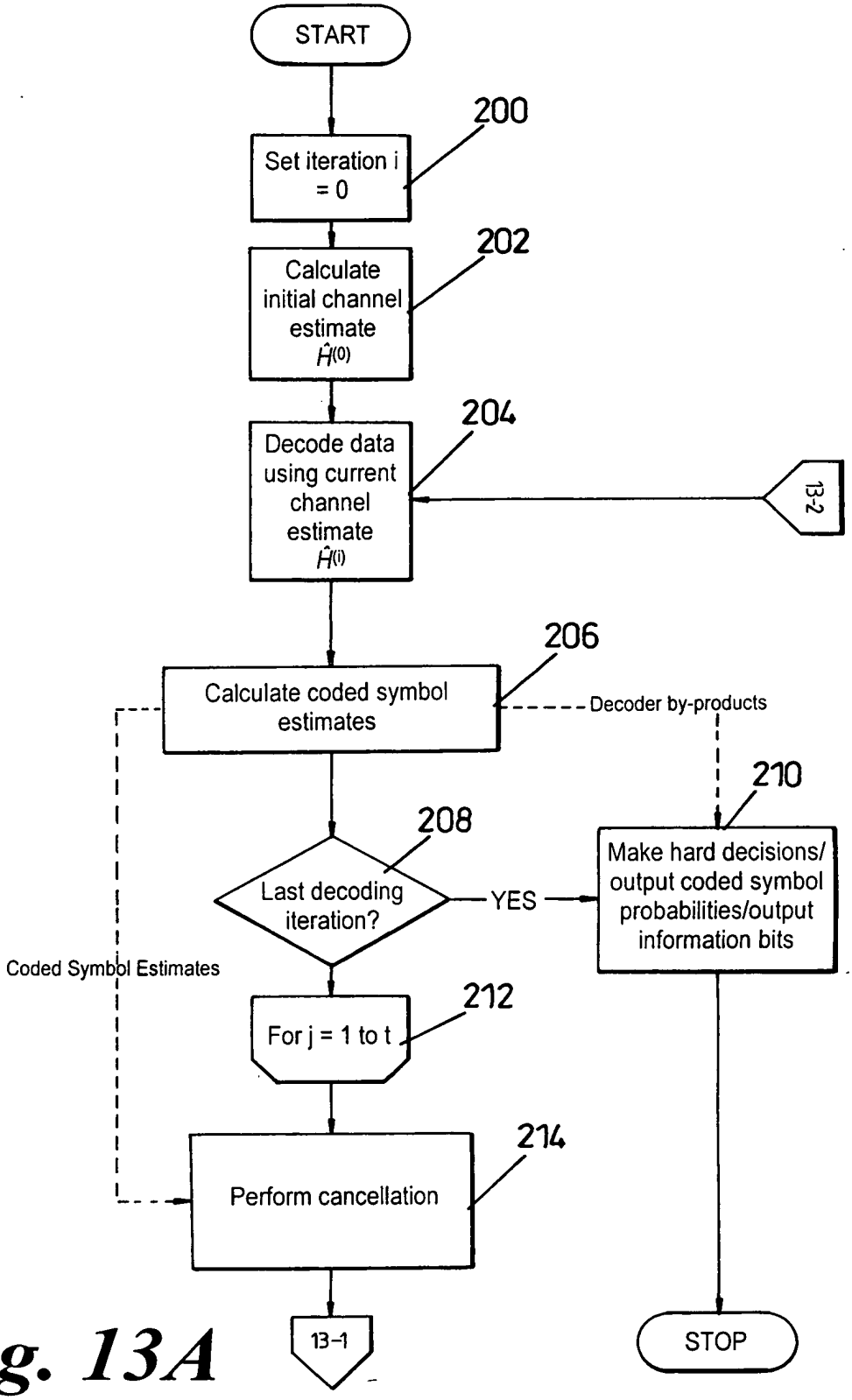

START
200
Set iteration i = 0
202
Calculate initial channel estimate $\hat{H}^{(0)}$
204
Decode data using current channel estimate $\hat{H}^{(i)}$
13-2
206
Calculate coded symbol estimates
Decoder by-products
210
208
Last decoding iteration?
YES
Make hard decisions/ output coded symbol probabilities/output information bits
Coded Symbol Estimates
212
For j = 1 to t
214
Perform cancellation
13-1
STOP

*Fig. 13A*

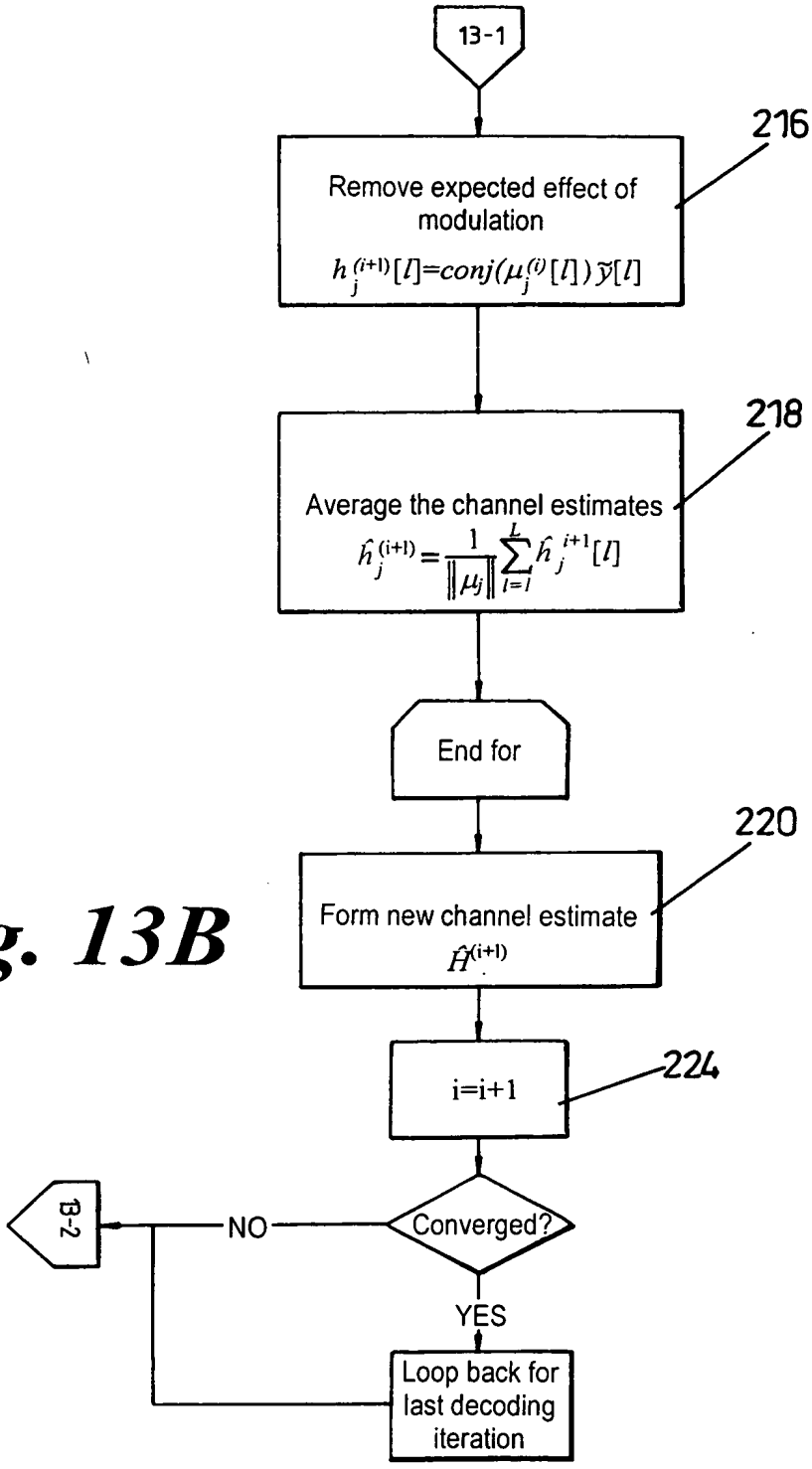

13-1
216
Remove expected effect of modulation
$h_j^{(i+1)}[l]=conj(\mu_j^{(i)}[l])\,\tilde{y}[l]$
218
Average the channel estimates
$\hat{h}_j^{(i+1)}=\frac{1}{\|\mu_j\|}\sum_{l=1}^{L}\hat{h}_j^{i+1}[l]$
End for
220
Form new channel estimate
$\hat{H}^{(i+1)}$
224
i=i+1
Converged?
NO
B-2
YES
Loop back for last decoding iteration

*Fig. 13B*

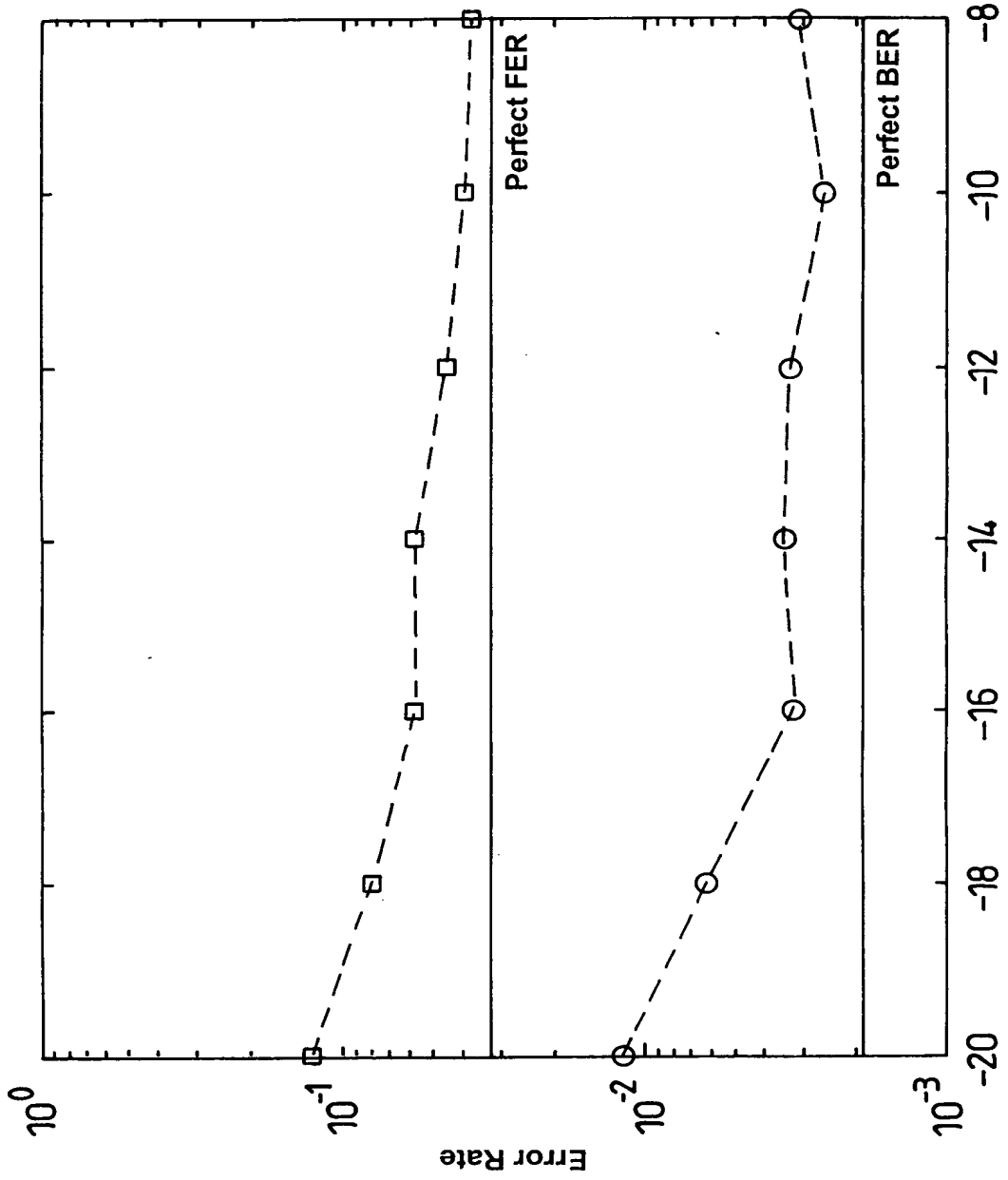

Perfect FER
Perfect BER
Error Rate
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
-8
-10
-12
-14
-16
-18
-20
Pilot to Signal Ratio, dB

*Fig. 14*

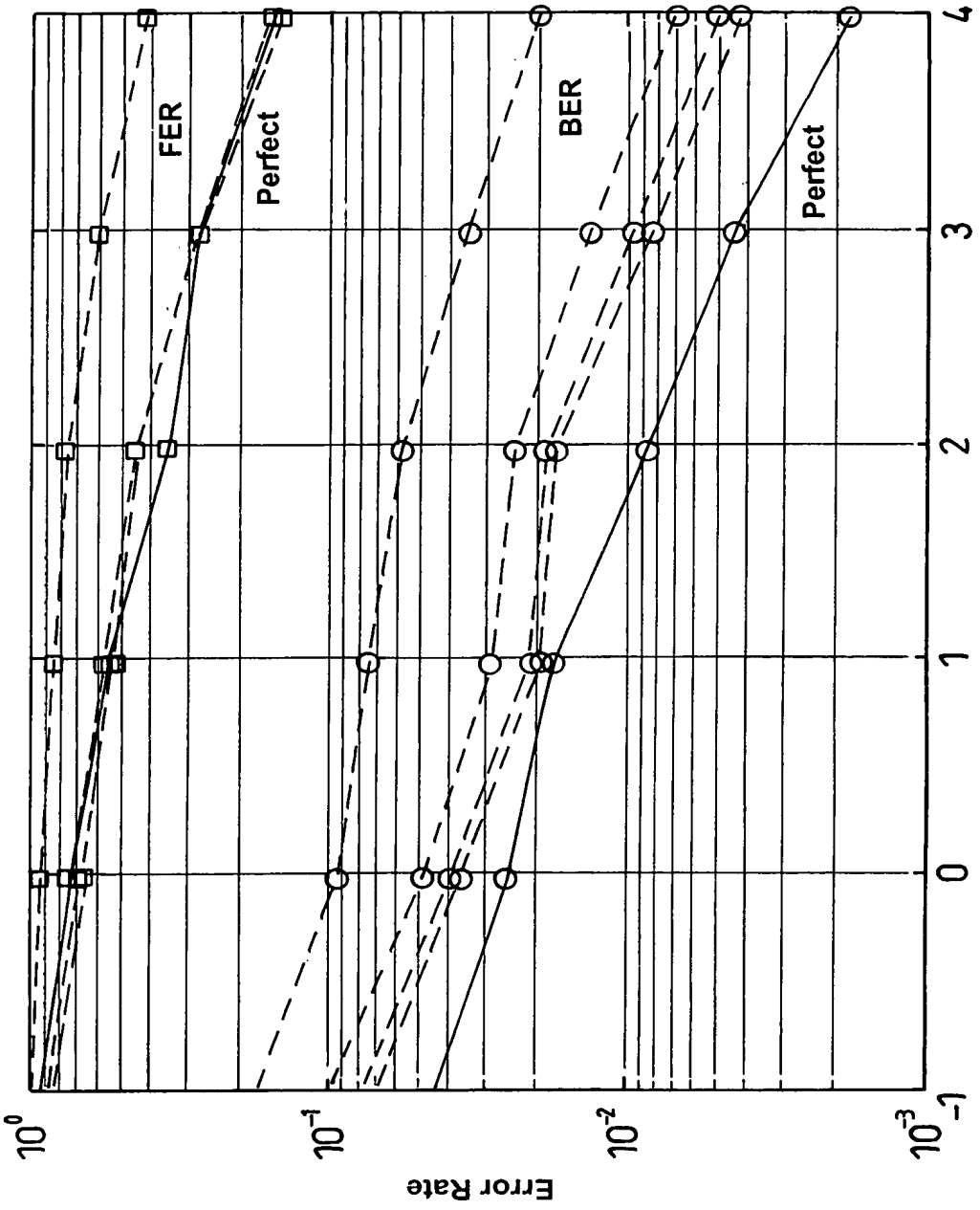

FER
Perfect
BER
Perfect
Error Rate
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
-1
0
1
2
3
4
Signal to noise ratio, dB

*Fig. 15*

| Constraint length K | Generators in octal | |
|---|---|---|
| 3 | 5 | 7 |
| 4 | 15 | 17 |
| 5 | 23 | 35 |
| 6 | 53 | 75 |
| 7 | 113 | 171 |
| 8 | 247 | 371 |
| 9 | 561 | 753 |
| 10 | 1,167 | 1,545 |
| 11 | 2,335 | 3,661 |
| 12 | 4,335 | 5,723 |
| 13 | 10,533 | 17,661 |
| 14 | 21,675 | 27,123 |

*Fig. 16*

REPLACEMENT SHEET

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| STC-Algorithm ($N_T$:$N_R$) | $E_b/N_o$ dB for 10% FER | Spectral Efficiency (bps/Hz) | $E_S/N_o$ (SNR) dB for 10% FER |
|---|---|---|---|
| Benchmark | | | |
| 1:1 | 11.0 | 1.0 | 11.0 |
| 1:2 | 4.5 | 1.0 | 4.5 |
| 1:4 | -0.5 | 1.0 | -0.5 |
| STTD (STBC) | | | |
| 2:1 | 7.2 | 1.0 | 7.2 |
| 2:2 | 2.2 | 1.0 | 2.2 |
| STTC-32 | | | |
| 2:1 | 11.0 | 2.0 | 14.0 |
| 2:2 | 4.6 | 2.0 | 7.6 |
| MC-STTC-256 | | | |
| 2:1 | 9.6 | 2.0 | 12.6 |
| 2:2 | 3.5 | 2.0 | 6.5 |
| 4:1 | 12.0 | 4.0 | 18.0 |
| 4:2 | 4.0 | 4.0 | 10.0 |
| 4:4 | -1.5 | 4.0 | 4.5 |
| BLAST | | | |
| uncoded 2:2 | 12.0 | 4.0 | 18.0 |
| coded 2:2 | 7.1 | 2.0 | 10.1 |

***Fig.17***

Notes:Notation $N_T$:$N_R$ is used to denote numbers of antennas at each end of the link.

a) $E_S$ denotes energy per transmitted STS

b) The benchmark is a 1/2-rate k=9 binary convolutional encoder,with output bits mapped to QPSK symbols. In a *static* 1:1 channel it achieves 10% FER for an $E_b/N_o$ of 2.2dB and 1% BER for an $E_b/N_o$ of 1.7dB.

c) The benchmark 1:4 number is approximate, as it has been extrapolated from results at a lower FER

d) 'STTD' is a concatenation of the benchmark encoder with the STTD block code

e) 'STTC-32' is the Tarokh STTC with 32 states, and two information bits per STS

f) 'MC-STTC-256' is a concatenation of the benchmark scheme, a QPSK modulation mapper, and a demux mapper to the different transmit antennas. It thus has $2^{k-1}$=256 states in the trellis, and a spectral efficiency which depends on the number of transmit antennas.

g) The variants of BLAST shown in the table use 'genie-aided' subtraction of the transmission from the stronger transmit antenna when detecting the transmission from the weaker.

h) The 'uncoded' BLAST case uses no error correction code (it is raw QPSK), hence it achieves a high spectral efficiency of 4 bps/Hz. The 'coded' case uses two separate 'benchmark' encoders, one for each antenna.

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| STC-Algorithm ($N_T$:$N_R$) | Spectral efficiency (bps/Hz) | Demodulator soft-metric (LLR) processing (MFLOPS) | Viterbi MLSE processing (MFLOPS) |
|---|---|---|---|
| Benchmark | | | |
| 1:1 | 1 | 0.9 | 198.4 |
| 1:2 | 1 | 2.5 | 198.4 |
| 1:4 | 1 | 5.0 | 198.4 |
| STTD (STBC) | | | |
| 2:1 | 1 | 2.5 | 198.4 |
| 2:2 | 1 | 5.0 | 198.4 |
| STTC-32 | | | |
| 2:1 | 2 | 8.7 | 12.4 |
| 2:2 | 2 | 17.4 | 12.4 |
| MC-STTC-256 | | | |
| 2:1 | 2 | 8.7 | 99.2 |
| 2:2 | 2 | 17.4 | 99.2 |
| 4:1 | 4 | 69.4 | 168.6 |
| 4:2 | 4 | 138.9 | 168.6 |
| 4:4 | 4 | 277.8 | 168.6 |
| 8:8 | 8 | 71,198 | 1276.4 |
| BLAST (coded) | | | |
| 2:2 | 2 | 0.02+2.5+1.2=3.7 | 198.4 |
| 4:4 | 4 | 0.7+5.0+3.7=9.4 | 198.4 |
| 8:8 | 8 | 24.8+9.9+8.7=43.4 | 198.4 |

***Fig. 18***